PREVENTATIVE MAINTENANCE TREATMENTS: DO THEY IMPACT SKID RESISTANCE ON LTPP SECTIONS?

Amir Abd El Halim, Ph.D., P.Eng.
Associate, Project Manager
Infrastructure Management and Pavement Engineering
Stantec Consulting

49 Frederick St.
Kitchener Ontario
N2H 6M7
519-585-7454
519-585-7495
Email: amir.abdelhalim@stantec.com

Susan Tighe, Ph.D., P.Eng.
Canada Research Chair in Pavement and Infrastructure Management, Professor
Dept. of Civil and Environmental Engineering
Department of Civil and Environmental Engineering
University of Waterloo
200 University Ave West
Waterloo Ontario Canada N2L 3G1
Tel: 519-888-4567 x 33512
Fax: 519-888-4300
Email: sltighe@civmail.uwaterloo.ca

Paper prepared for presentation
at the Pavement Maintenance and Preservation Session
of the 2010 Annual Conference of the
Transportation Association of Canada

Halifax, Nova Scotia

ABSTRACT

Conventional or routine pavement maintenance practices can be characterized as reactive in nature and not very cost effective. Preventative maintenance is an essential component of an effective pavement management framework or strategy. Dollars invested in implementing preventative maintenance strategies are significantly less than allowing a pavement structure to deteriorate until major pavement rehabilitation or reconstruction is required.

Quantifying the effectiveness or performance of a Maintenance, Rehabilitation or Reconstruction (M, R, & R) activity is beneficial to an agency so they can determine what treatments or strategies offer the best "bang for the buck". Historically, pavement condition or performance is traditionally represented by its functional or structural performance. From a safety standpoint, the level of safety of a pavement has typically been measured as a function of its skid resistance.

The Long Term Pavement Performance (LTPP) database can provide a reliable source of pavement data for assessing the performance of M, R, & R activities. The LTPP database has an extensive skid data set from sites located across Canada and the United States. As a part of this study, friction data from all SPS-5 sites in the LTPP experiment was used to examine skid resistance over time across various environment zones. The SPS-5 experiment examines the effects of various rehabilitation activities on flexible pavement sections. Another component of the study was to evaluate the performance of a number of commonly implemented preventative maintenance strategies. This paper presents a framework or methodology that can be used to evaluate the safety effectiveness of a pavement preservation strategy using LTPP data.

BACKGROUND

One of the most important indicators of level of service for a highway network is safety. Each year, thousands of motorists across North America are involved in motor vehicle collisions, which result in property damage, congestion, delays, injuries and fatalities. The Ontario Ministry of Transportation estimated that in 2002, vehicle collisions in Ontario cost the province nearly $11 billion. It also estimated that for every dollar spent on traffic management, 10 times that amount could be saved on collision-related expenditures, including health care and insurance claims [6].

Conventional or routine pavement maintenance practices can be characterized as reactive in nature (unplanned), performed on failing pavements, does not contribute to long-term performance, not cost effective and often performed under harsh or severe conditions [1]. Preventative maintenance is an essential component of an effective pavement management framework or strategy. Preventative maintenance can be defined as a strategy intended to arrest light deterioration, retard progressive failures, and reduce the need for routine maintenance and service activities (Louis O'Brien, NCHRP 153). Dollars invested in implementing preventative maintenance strategies are significantly less than allowing a pavement structure to deteriorate until major pavement rehabilitation or reconstruction is required.

The benefits of practicing preventative maintenance are higher customer satisfaction, better informed decisions, improved strategies and techniques, improved pavement condition, reduced life cycle costs and increased safety. Studies have shown that highway improvements such as increasing the radius of a horizontal curve or increasing the skid resistance of a pavement can result in a reduction in the number of collisions and improved levels of service. Evaluating the effectiveness or performance of a Maintenance, Rehabilitation or Reconstruction (M, R, & R) activity is beneficial to agencies and contractors so they can determine what treatments or strategies offer the best "bang for the buck".

From a safety standpoint, the level of safety of a pavement has typically been measured as a function of its skid resistance. A strong relationship exists between safety, highway design and pavement performance. Outdated and poor geometric design practices along with deteriorated pavement conditions influence the safety of highway alignments. In the United States, over 43,000 fatalities occur on the nation's roadways and 30% of all fatal highway collisions can be attributed to these factors [2].

Surface Friction

Surface friction between the tire of the vehicle and the pavement surface has a profound affect on highway safety. A driver must be able to adapt their behavior to changing friction conditions in order to maintain an acceptable level of safety [7]. When road surfaces are dry, the friction generated between the tires and pavement is generally sufficiently high to provide adequate levels of safety. During wet or winter weather conditions, water can create a critical situation by increasing the potential for hydroplaning or skidding, especially when skid resistance of a pavement is low [8]. When skid resistance is low, the driver may not be able to stop the vehicle or retain stability on wet pavement. Skid resistance is defined as the force that resists the sliding of tires on a pavement when the tires are prevented from rotating.

The impact of surface friction on highway safety is a very complex problem. It consists of a relationship that involves the driver and vehicle, environmental conditions, and the pavement surface. The ability of a driver to accurately assess or estimate the friction conditions is poor [7]. This perspective is supported by several research studies such as speed measurements during different roadway conditions, driver interviews during slippery conditions, and vehicle simulator experiments. The main premise for these studies is that if the stopping distance for dry pavement conditions is considered an indicator of safe speed, then a reduction in speed as a result of poor surface friction (wet or icy conditions) should result in an equivalent stopping distance [3]. A study was carried out where vehicle speeds were recorded under different road conditions. For the studied highway (7-m wide, posted speed of 90 km/h), the average speeds were found to be 85 km/h to 95 km/h for dry pavement conditions. During winter conditions, a 6 to 10 km/h decrease in the posted speed limit was recorded despite icy and snow packed pavement conditions. To maintain equivalent "dry" pavement surface stopping distances, the speed of the vehicle should have been reduced to 56 km/h [7].

Several other studies have shown similar findings. A number of research studies examining collision data and surface friction in European countries such as the Netherlands, Germany, and France have shown that the number of collisions and the relative proportion of collisions at skid-prone sites increase sharply when the friction coefficient decreases. For example, when the level of friction is 0.35 to 0.44, the collision rate is 0.20 (personal injuries/million veh-km). When the level of friction is less than <0.15, the collision rate increases by 300%. Recent research has shown the benefits of mix design and hot mix asphalt technologies on the surface friction of newly constructed pavements [9]. A review of the literature reveals that there are no specific guidelines when it comes to acceptable levels of surface friction. However, pavements with a skid number (SN) below 35 could potentially be problematic from a safety standpoint [10]. The Transportation Association of Canada (TAC) recommends that a pavement section with a skid number below 32 is a potential risk and preventative maintenance should be considered [11].

The Long Term Pavement Performance (LTPP) Project

The Long Term Pavement Performance (LTPP) Project is the largest pavement research study performed in North America. Pavement performance data has been collected from over 2,400 pavement sections located across Canada and the United States. These pavement sections consist of a variety of pavement structures in various environmental zones, built on different subgrades and exposed to various levels of traffic.

The LTPP program was initiated in 1987 as a part of the Strategic Highway Research Program (SHRP). The main objective for the LTPP program is to establish a national long-term pavement database to support SHRP objectives and future needs. Currently, the project is managed by the Federal Highway Administration (FHWA) and consists of over 2,400 sections at 932 locations on in-service highways located across North America. The LTPP test sections are classified into a number of studies; General Pavement Studies (GPS) and Specific Pavement Studies (SPS) sections. A GPS test site typically would have one test section, while an SPS test site would have multiple test sections incorporating a controlled set of experiment design and construction features [**Error! Reference source not found.**].

LTPP data is collected in a consistent manner at a specific level of accuracy and checked through a series of Quality Assurance (QA) checks. Also, maintenance activities are monitored and recorded, thus addressing some of the possible sources of inconsistencies in historic performance data.

STUDY APPROACH

To quantify the effectiveness of a preventative maintenance strategy, historical pavement performance data is required. Pavement performance data such as deflection measurements collected from a Falling Weight Deflectometer (FWD), roughness in terms of the International Roughness Index (IRI) and skid resistance can be used to evaluate the effectiveness of an M, R, & R treatment. Most of this data has been collected over the past 20 years as a part of the LTPP Project and is stored in the LTPP DataPave database.

When determining the performance or improvement provided by an M, R & R treatment, two important factors must be known. First, the condition of the pavement just prior to implementing the M, R, & R treatment must be known. In an ideal situation, this data is collected or surveyed just prior to construction. Secondly, the condition of the pavement just after the implementation of the M, R & R treatment must be identified. Ideally, this data should be collected after construction, sometime after the pavement has been re-opened to traffic. With the before-and-after condition of the pavement known, the improvement, or increase in structural, functional or safety performance can be quantified. The LTPP database is an excellent source of before-and-after pavement performance data.

Data Manipulation

As stated earlier, the LTPP database includes an extensive amount of data, designed to address the requirements of a large variety of pavement research objectives. Subsequently, only the data required for this study was extracted from the LTPP database for analysis purposes. Furthermore, some of the data had to be filtered and/or reformatted for analysis purposes. The data used in the analysis and their sources in the LTPP database is shown in Table 1. For the collection of friction data from the LTPP sites, a skid number is recorded at the start and end of the 500 foot section. For analysis purposes, the skid number for the start and end were averaged.

The construction activities in the LTPP are defined at a very detailed level to allow for further research into specific treatments. This includes details in the maintenance activities, such as overlays or surface treatments that were implemented on the sections after the original rehabilitation activity. These maintenance activities will have an impact on the pavement performance. Therefore, the performance data considered in the analysis were those collected before and after the M, R & R activities were initiated. When an LTPP site is first entered into the study, it is identified as Construction Number 1. When the test site undergoes an M, R &R treatment, it changes Construction

Numbers from 1 to 2. The reason for the change is also documented by a code which represents the various M, R, & R treatments.

TABLE 1 Data Types and Sources from LTPP Database

Data Type	LTPP DataPave Module	LTPP Table Name
Construction Date and M&R activities type.	Administration	EXPERIMENT_SECTION
Pavement type, lane width, and other general information	Inventory	INV_GENERAL
Section location, route number, mileposts.	Inventory	INV_ID
Historical precipitation data.	Climate	CLM_VWS_PRECIP_ANNUAL
Historical temperature data.	Climate	CLM_VWS_TEMP_ANNUAL
Friction (SN) measurements.	Pavement monitoring	MON_FRICTION

One of the major parameters that influence pavement performance is environmental and climatic factors. The LTPP was primarily designed considering 4 environmental zones, as combination of wet versus dry, and freeze versus no freeze. These classifications are based on the amount of annual precipitation and freezing index. Climatic data in terms of annual precipitation and historical temperature data were extracted from the LTPP database to evaluate the environmental zone. Depending on the agency requirements, the limits defining the environmental zone can be changed. However, for the scope of this case study, the environmental zones were defined based on the limits set by the FHWA, which are a freezing index of 83 degree C-days as a boundary between No-Freeze and Freeze zones, and a precipitation of 50 mm/year as a boundary between Wet and Dry zones.

EXAMINATION OF SKID RESISTANCE OVER TIME

Data from all SPS-5 sites in the LTPP experiment where used for this analysis. The SPS-5 experiment examines the effects of different rehabilitation activities on flexible pavement sections. Each SPS-5 test site will have 8 flexible pavement sections with different rehabilitation activities, in addition to a control section. Friction data from all SPS-5 sites in the LTPP experiment was used in the analysis. The rehabilitation activities implemented in each SPS-5 are:

- Thin AC overlay
- Medium AC overlay
- Cold Mill + Thin AC Overlay
- Cold Mill + Medium AC Overlay
- Thin Recycled AC Overlay
- Medium Recycled AC Overlay
- Cold Mill + Thin Recycled AC Overlay
- Cold Mill + Medium Recycled AC Overlay

In total data from 14 SPS-5 sites with a total of 165 test sections was evaluated. Table 2 shows the location, year of construction, and environmental zone, as described in the LTPP database, for these test sites. The friction data for the SPS-5 test sites along with the corresponding environment zone were extracted from the LTPP database. Data for a single Construction Number was examined to eliminate the affects of an increase in SN due to an M, R & R treatment.

A model that best fits the data for each environment zone was developed (Figures 1 to 4). For three of the environment zones, Dry No Freeze, Wet Freeze, and Wet No Freeze, the level of friction is observed to increase with time. The Dry Freeze environment zone shows a slight decrease in time. It is important to note the size (magnitude) of the slope for each model, which generally indicates a very low or flat relationship. This result is similar to a study conducted by Indiana Department of Transportation (IDOT, ref). This trend was also observed when examining the friction data across all environment zones (Figure 5).

TABLE 2 LTPP SPS 5 Test Sites

SPS-5 Site	State/Province	Year of Construction	Environmental Zone
010500	Alabama	1991	Wet - No Freeze
040500	Arizona	1990	Dry - No Freeze
060500	California	1992	Dry - No Freeze
080500	Colorado	1991	Dry - Freeze
120500	Florida	1995	Wet - No Freeze
130500	Georgia	1993	Wet - No Freeze
230500	Maine	1995	Wet - Freeze
240500	Maryland	1992	Wet - Freeze
300500	Montana	1991	Dry - Freeze
340500	New Jersey	1992	Wet - Freeze
350500	New Mexico	1996	Dry - No Freeze
400500	Oklahoma	1997	Wet - No Freeze
810500	Alberta	1990	Wet - Freeze
830500	Manitoba	1989	Wet - Freeze

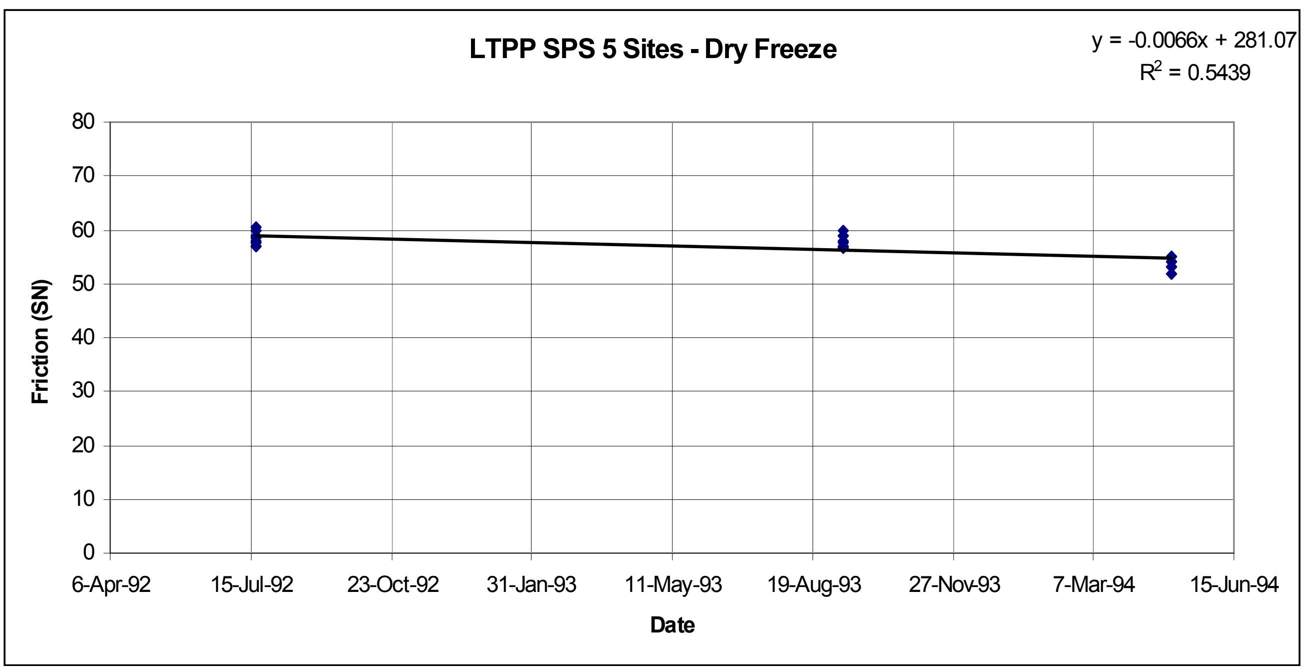

Figure 1. Skid Resistance over time for Dry Freeze Environmental Zone

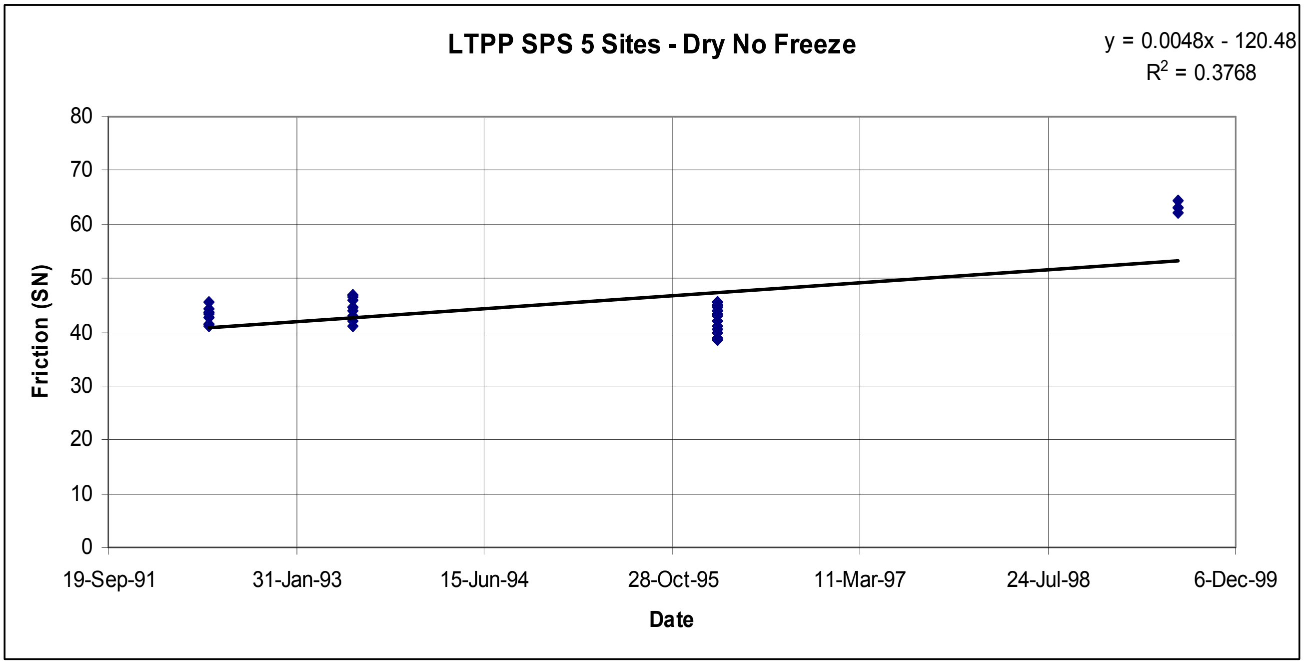

Figure 2. Skid Resistance over time for Dry No Freeze Environmental Zone

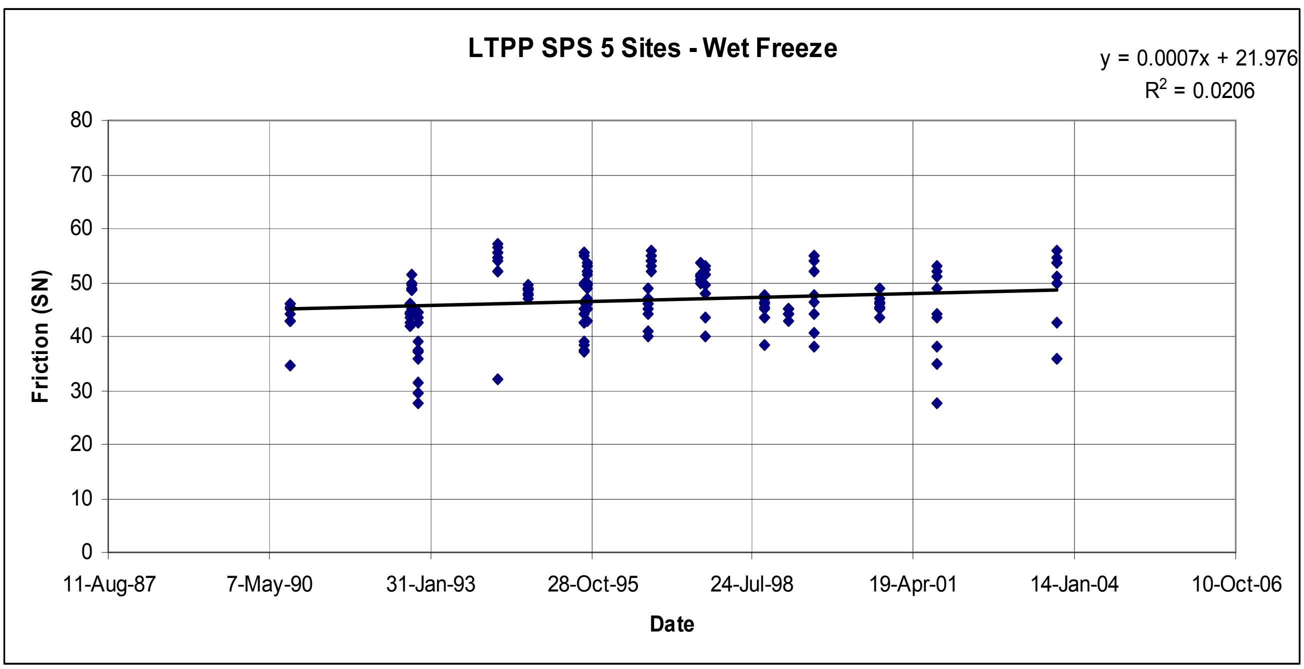

Figure 3. Skid Resistance over time for Wet Freeze Environmental Zone

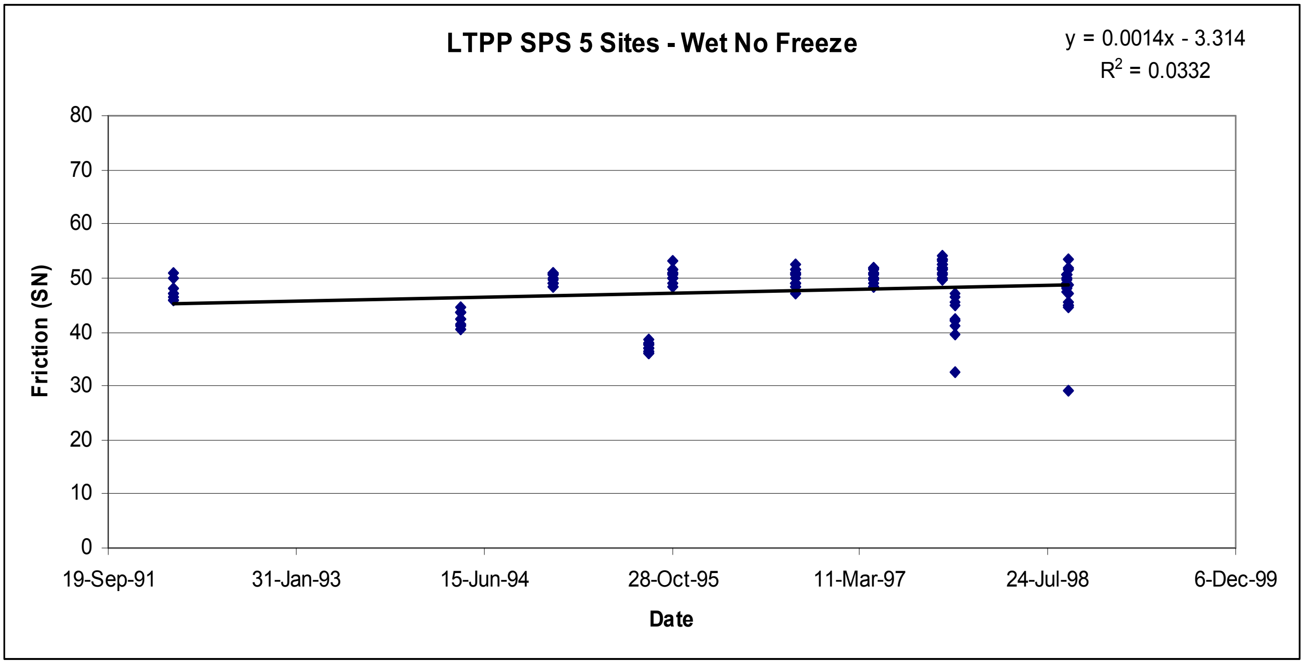

Figure 4. Skid Resistance over time for Wet No Freeze Environmental Zone

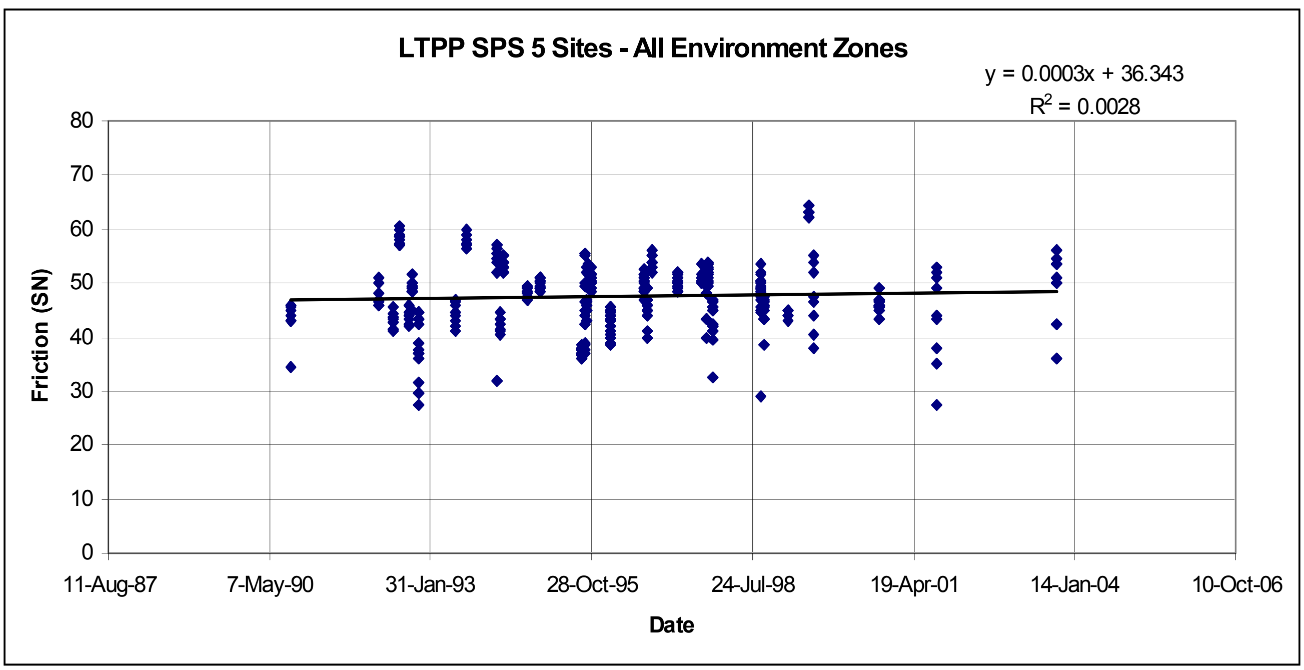

Figure 5. Skid Resistance over time for All Environmental Zones

It is expected that a pavement will deteriorate with time as a result of traffic loadings and climatic factors. Structural performance quantified in terms of a Structural Adequacy Index (SAI) obtained from deflection measurements generally decreases with time. Pavement distresses such as alligator cracking, longitudinal and transverse cracking and rutting also initiate and propagate with time. Functional performance such as ride quality described in terms of roughness (IRI) obtained from a high speed profiler will increase (worsen) with time.

It would be expected that skid resistance would also decrease with time due to traffic and climatic factors similar to structural or functional performance. However, this was not observed with friction measurements. This can be explained due to the fact that as a pavement ages and the surface starts to exhibit signs of distress such as raveling, the surface texture of the pavement may actually become rougher. This is an important factor to consider when examining historical friction trends, conducting life cycle cost analysis, and developing pavement performance models.

QUANTIFYING THE SKID RESISTANCE PERFORMANCE OF M, R & R TREATMENTS

To quantify the skid resistance performance of various M, R & R treatments, friction data was extracted from the DataPave database. LTPP data from the MON_FRICTION table was used for the analysis. Data from all flexible pavement sections in the LTPP experiment which had recorded friction data was used in the analysis. Data from the EXPERIMENT_SECTION table provided information related to the M, R & R treatment including the year it was implemented for each of the LTPP sections. In total data from 347 LTPP sites were examined as a part of this analysis.

The various LTPP sections were then categorized by M, R & R treatment. Since combinations of maintenance activities are typically performed at a single time (i.e., crack sealing, shoulder repair and asphalt concrete overlay), the treatments were aggregated into major groups. Using information obtained from the EXPERIMENT_SECTION Table, the following M, R & R treatment groups were developed:

- AC Overlay
- Recycled AC Overlay
- Mill and AC Overlay
- Slurry Seal Coat
- Aggregate Seal Coat
- Sand Seal Coat
- Fog Seal

The friction data was then filtered and split into two unique data sets. The first data set included all friction data obtained from Construction Year 1 (or prior to the M, R & R Treatment). The last recorded friction measurement was filtered and used to represent the level of friction prior to construction.

The second data set included all friction data obtained from Construction Year 2 (or after M, R&R Treatment). The first recorded friction measurement was filtered and used to represent the level of friction after construction.
The difference between these two friction measurements represents the impact of the M, R & R activity on the level of friction. The percent change in friction level was then calculated for each LTPP site. This was calculated from the following equation:

$$Percent\ Change\ in\ SN = (SN_{after} - SN_{prior})/SN_{prior} \quad [1]$$

The average percent change in SN was calculated for each M, R & R treatment group. This value represents the overall impact of applying the various M, R &R treatments on the level of skid resistance.

The analysis was performed at three different levels. For the first level, the pre- and post-construction skid numbers were examined for all flexible LTPP sections and the average group treatment level was calculated. The duration between skid testing cycles from was observed to vary from 0 years to 13 years after construction. As a result, for the second level of analysis, only the LTPP sections with less than 5 years between the pre- and post-construction skid numbers were included in the analysis. Upon further examination of the data, it was observed that a number of LTPP sections showed a decrease in the level of friction as a result of the M, R, & R treatment. This could be attributed to a number of factors such as an invalid SN, skid testing performed during different times of the year (seasonal impacts such as wet weather), operator error, etc. As a result, the third level of analysis examined LTPP sections with less than 5 years between the pre- and post-construction skid numbers and sections that showed an improvement in SN as a result of the various M, R & R treatments.

Summary statistics were determined for each M, R & R group and the results are presented below in Tables 3 and 4 for the pre- and post-construction conditions. The percent change in SN condition for each M, R & R group for the three levels of analysis is presented in Table 5.

TABLE 3. Summary Statistics for Pre-Construction SN Condition

Treatment	Minimum SN	Maximum SN	Average SN	Standard Deviation
AC Overlay	19.0	90.0	43.2	12.3
Recycled AC Overlay	32.0	*69.0*	45.1	9.6
Mill and Overlay	15.0	67.0	42.8	15.0
Slurry Seal Coat	23.0	63.0	43.2	11.8
Aggregate Seal Coat	42.0	44.0	43.0	1.4
Sand Seal Coat	36.0	60.0	45.0	11.3
Fog Seal	30.0	84.2	44.8	9.7

TABLE 4. Summary Statistics for Post-Construction SN Condition

Treatment	Minimum SN	Maximum SN	Average SN	Standard Deviation
AC Overlay	27.0	99.0	45.4	10.1
Recycled AC Overlay	34.0	*65.0*	46.9	7.4
Mill and Overlay	31.3	85.0	46.6	8.0
Slurry Seal Coat	42.0	66.0	54.6	6.4
Aggregate Seal Coat	25.5	61.8	44.7	10.3
Sand Seal Coat	54.0	56.0	55.0	1.4
Fog Seal	37.0	61.0	45.6	11.1

TABLE 5. Percent Change in SN

Treatment	Level 1 % Change	Level 2 % Change	Level 3 % Change
AC Overlay	8	10	27
Recycled AC Overlay	5	6	14
Mill and Overlay	6	8	17
Slurry Seal Coat	20	22	33
Aggregate Seal Coat	0	-1	30
Sand Seal Coat	25	25	25
Fog Seal	1	1	4

DISCUSSION OF RESULTS

As can be observed from Table 5 (Level 3), the largest increase in SN was for the Slurry Seal Coat and Aggregate Seal Coat treatment Groups. Both of these treatments can be characterized as a surface treatment. The lowest increase in SN was for the Fog Seal Group. This is justifiable since a Fog Seal generally results in a smoother surface with lower surface friction. The Asphalt Concrete Overlay Group had an increase of 27% and was found to be greater than asphalt overlays which contained recycled asphalt concrete (14%).

An important factor to highlight is that even though Surface Treatments (Slurry and Aggregate Seal Coats) offer similar or greater performance to the AC Overlay or Mill and Overlay treatments at lower costs, the service life for the surface treatments is typically lower. For example, on a roadway with high traffic volumes, the service life for a surface treatment could be 1 to 2 years, where an Asphalt Overlay or Mill and AC Overlay could be 7 to 10 years. A Life Cycle Cost Analysis (LCCA) that identifies the most cost effective M, R & R strategies for the given pavement structure which considers all design parameters and site conditions should be performed prior to selecting and implementing the treatment.

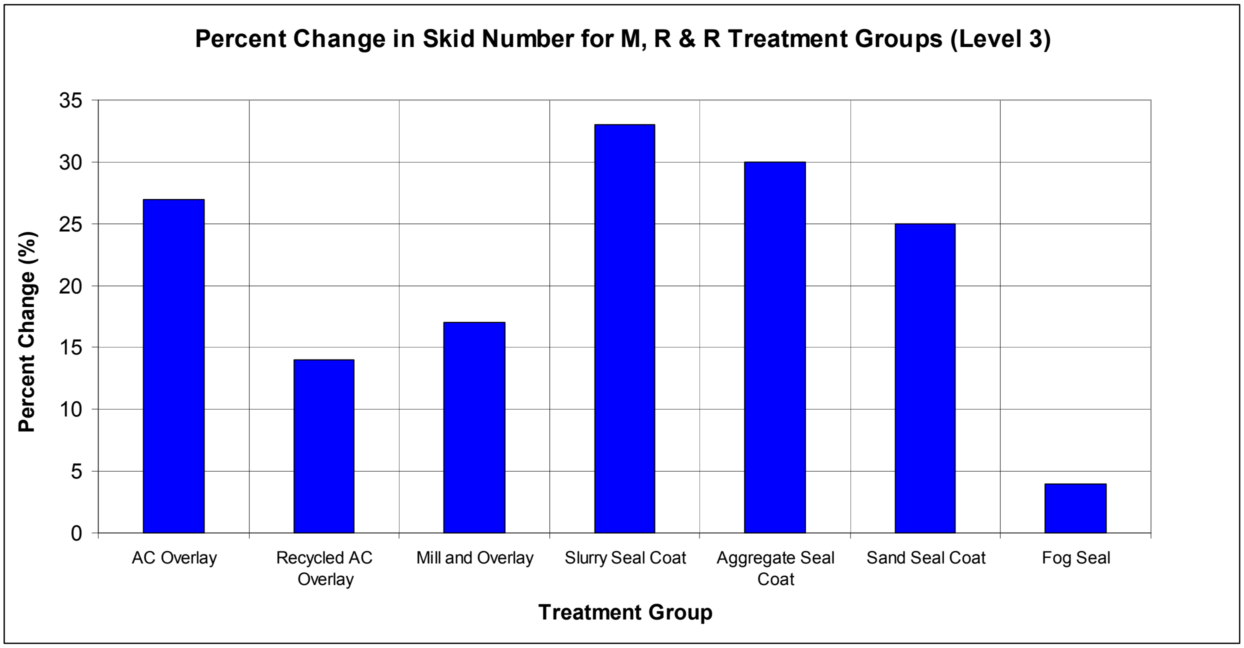

Figure 6. Percent Increase in SN for Various M, R and R Treatments

SUMMARY

Despite that fact that the preventative maintenance concept has been around for several decades, a number of transportation agencies still practice the old reactive approach despite the obvious benefits to life cycle costs. As safety is becoming more of a concern on our nation's highways and the number of collisions continues to increase, agencies will be examining methods and techniques to increase the level of safety of their pavements and highway alignments. The level of safety of a pavement has typically been measured as a function of its skid resistance. A strong relationship exists between safety, highway design and pavement performance.

Studies have shown that highway improvements such as increasing the radius of a horizontal curve or increasing the skid resistance of a pavement can result in a reduction in the number of collisions and improved levels of service. The costs of increasing the radius of a horizontal curve or widening a highway alignment tend to be significantly higher than a preventative maintenance activity such as an Asphalt Concrete Overlay or a Surface Treatment. Evaluating the effectiveness or performance of an M, R, & R treatment is beneficial to agencies and contractors so they can determine what treatments or strategies offer the best "bang for the buck".

Skid data is not readily available to researchers or the public due to the sensitivity of the data and the potential risk to the agency (lawsuits and litigation). The LTPP database provides engineers and researchers with a valuable source of high quality historical pavement performance data that can be used to evaluate pavement performance. The LTPP database has an extensive skid data set from sites located across Canada and the United States.

The objectives of this study were to examine the friction data from all LTPP SPS-5 test sites to examine skid resistance over time across various environment zones and to evaluate the performance of a number of commonly implemented preventative maintenance strategies.

CONCLUSIONS AND RECOMMENDATIONS

Based on this research study, the authors present the following conclusions and recommendations.

- A pro-active approach is required to deal with the friction-collision problem. Preventative maintenance should consider safety in the project selection process since the treatment can improve the level of safety of a pavement or highway alignment.
- The analysis framework developed as a part of this research study can be applied to examine the performance of preventative maintenance treatments in terms of ride quality (IRI), pavement distress and structural adequacy (FWD testing). This pavement performance data is also readily available in the LTPP DataPave database.
- Network level friction testing should be carried out on an annual or bi-annual basis to screen the highway network and identify potential collision prone locations. These locations are potential candidates for implementing safety related preventative maintenance.
- Life Cycle Cost Analysis should be performed to determine the most cost effective Preventative Maintenance Technique given all project and site conditions.
- When skid data cannot be readily accessible for research purposes, the LTPP data set provides an extensive and reliable source of data.

AKNOWLEDGEMENTS

The authors would like to thank The University of Waterloo and the Centre for Pavements and Applied Transportation Technology (CPATT) for support.

REFERENCES

1. Civil Infrastructure Systems Technology Road Map (2003-2013), Canadian Society of Civil Engineers (CSCE), Electronic Report: http://www.csce.ca/TRM/TRM-Report_english_01.pdf.

2. Report Card for America's Infrastructure, American Society of Civil Engineering (ASCE), VA, USA, 2005, http://www.asce.org/files/pdf/reportcard/2005reportcardpdf.pdf.

3. The World Fact book 2007, Central Intelligence Agency (CIA), ISSN 1553-8133, Virginia USA, 2007.

4. The Encyclopaedia of the Nations – Canada, 2006. website: http://www.nationsencyclopedia.com/Americas/Canada.html

5. Office of the Auditor General of Ontario. "2004 Annual Report of the Office of the Provincial Auditor of Ontario", Ontario, Canada, 2004.

6. Office of the Auditor General of Ontario. "2005 Annual Report of the Office of the Auditor General of Ontario, Chapter 3, VFM Section 3.12, 2005.

7. Wallman, C., G. and Astrom, H. Friction Measurement Methods and The Correlation Between Road Friction and Traffic Safety – A Literature Review. Swedish National Road and Transport Research Institute. VTI meddelande 911A-2001, Sweden, 2001.

8. Shahin, M., Y. *Pavement Management for Airports, Roads, and Parking Lots*. Chapman and Hall, New York, USA, 1994.

9. Poulikakos, L., D., Gubler, R., and Partl, M., N. Current State of Porous Asphalt in Switzerland, ISAP, International Conference on Asphalt Pavements, Quebec City, 2006.

10. Noyce, David A., Bahia, Hussain U., Yambo, Josue., Chapman, Jeremy., Bill, Andrea R. Incorporating Road Safety into Pavement Management: Maximizing Surface Friction for Road Safety Improvements, MRUTC 04-04; Report No. 2007-005, Wisconsin, 2007

11. Transportation Association of Canada. *Pavement Design and Management Guide*, Ottawa, Canada, 1997.